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Published in:

Mobile Wireless Middleware, Operating Systems, and Applications - Workshops

DOI (link to publication from Publisher):

[10.1007/978-3-642-03569-2_16](https://doi.org/10.1007/978-3-642-03569-2_16)

Publication date:

2009

Document Version

Early version, also known as pre-print

[Link to publication from Aalborg University](#)

Citation for published version (APA):

Heide, J., Pedersen, M. V., Fitzek, F., & Larsen, T. (2009). Connecting the islands - enabling global connectivity through local cooperation. In *Mobile Wireless Middleware, Operating Systems, and Applications - Workshops* (pp. 135-141). Springer. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering No. 12 https://doi.org/10.1007/978-3-642-03569-2_16

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Connecting the Islands - Enabling Global Connectivity through Local Cooperation

Janus Heide, Morten V. Pedersen, Frank H. P. Fitzek, and Torben Larsen

Aalborg University, Aalborg, Denmark, Dept. of Electronic Systems
`{speje|mvpe|ff|tl}@es.aau.dk`

Abstract. In this work we consider the interconnection of islands formed by neighbouring devices in a highly dynamic topology. To allow for high mobility we take offset in a purely wireless infrastructure where all devices incorporate a global and a local wireless communication interface. We consider cooperation as a means to improve the utilization of these interfaces. Furthermore we reflect on the use of network coding as a technique for decreasing the complexity of cooperative strategies and presents obstacles that must be addressed before network coding can be deployed.

Key words: Cooperation, Network Coding, Ubiquitous Networks, Wireless Networks.

1 Introduction

Several future visions on computer network usage and accessibility include the concept that the usability of most things can be improved through the use of an ubiquitous network connection. In particular a connection that is always available and which require less interacting from the user. Such a vision imposes new requirements on the underlying network architecture and may require that networks are deployed differently than what is the norm today.

If devices are required to maintain an autonomous and continuously connection the only solution is to incorporate some form of global wireless communication interface. We note that the notion of a global connection is relative, for example a mobile phone can be considered as globally connected, but there will of course be locations where there is no coverage. This holds for all communication systems. Typically one drawback of a long range wireless communication system is the relative low capacity. In most current mobile phones this issue has been mitigated by incorporating a high speed short range wireless and/or wired communication interface. Thus the user can use the local connection when available and is at the same time always guaranteed service through the global connection although at a reduce speed. Thus the premises in this work is that all/most devices have one fast short range interface and one slow long range interface. Figure 1 shows three islands of devices with global and local communication links. The devices that form these islands will not remain stationary and thus the map of the islands will constantly change; new islands will appear,

islands will drift or change shape, and islands will disappear. This underlines the need for a wireless infrastructure as wired networks does not allow the necessary mobility.

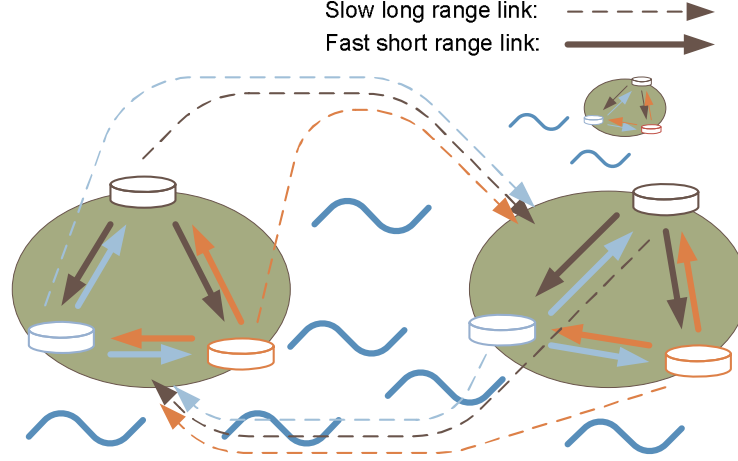


Fig. 1: Devices close to each other communicate via their local interface and form an island, the global interface is used for communication with devices further away on other islands.

In this type of wireless topology resources such as spectrum and energy are typically limited as the wireless medium is shared and devices are battery-driven. To use these resources more efficiently we can deploy cooperative strategies as they can take advantage of the differences between the local and global links. Cooperation can increase the throughput in cases where all devices on one island do not perform global communication simultaneously or wish to send or receive correlated information. With cooperation idle global links can be shared with neighbouring devices and thus the spectrum resource can be better utilized. If devices need correlated information they can share the burden of receiving the content and exchange their part of the information afterwards. Cooperation can also be used to reduce energy consumption. Consider the case where the standby power of the global link is significantly higher than for the local link. Here one device may take up a leader role and the burden of listening on the global link while the other devices turn off their global wireless link and thus conserve energy. If the leader detects that data is being transmitted to one of the devices with turned off global interface it may wake up that device via the local link.

Many such cooperative techniques have already been investigated and proven [1]. Thus the use of cooperation seems like a promising candidate for improving the communication. A cooperative system introduces a number of challenges and problems especially if the network topology is very dynamic.

2 Cooperation

The properties of the global channel influence how cooperation should be performed. In particular if the link of the different devices are independent or not.

If the global links are not independent devices on the island should not transmit simultaneously as the transmissions will otherwise collide. In this case cooperation can be used to distribute the burden of long range transmission among the devices on the sending island and thus share their energy resource. Alternatively the throughput can be increased if all devices on the receiving island overhear the transmissions from the source. If the sink losses a packet it is possible that one of the other devices on the island received it and in that case the sink may fetch the packet via its fast local connection. This form of cooperation is typically referred to as forwarding.

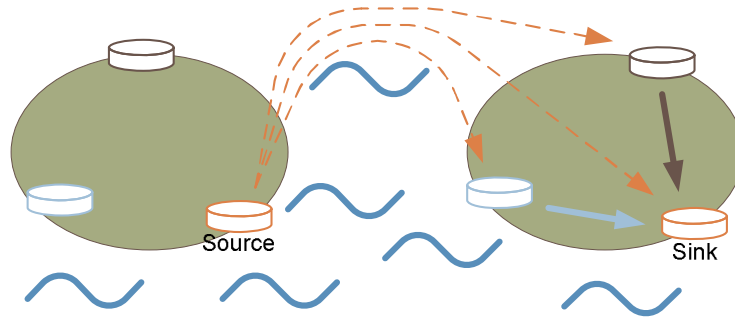


Fig. 2: The source transmits to the sink and the neighbouring devices of the sink cooperate with the sink.

If the global links are independent the devices on the sending island may aid the source in transmitting in order to increase the throughput. One approach is to let the source spread the data to all devices on its island via its fast local interface. All devices on the island can then transmit parts of the data simultaneously and thus speedup the transmission. On the receiving island different devices can receive different parts of the data and forward it to the sink. This form of cooperation is often referred to as content-splitting.

Such cooperative approaches seems interesting as they potentially offer significant benefits e.g. increase in the transmission speed, increased reliability, and reduced energy consumption. However they also pose a number of challenges. One important problem is that all nodes need information about the topology, e.g. the source needs to know how to split the data and where to transmit it. In a simple network this type of knowledge can be maintained with a relatively low overhead but as the size and complexity of the topology increases so does the overhead. To remove the need for this information and reduce the complexity of the control system that guards the cooperation we consider the use of network coding.

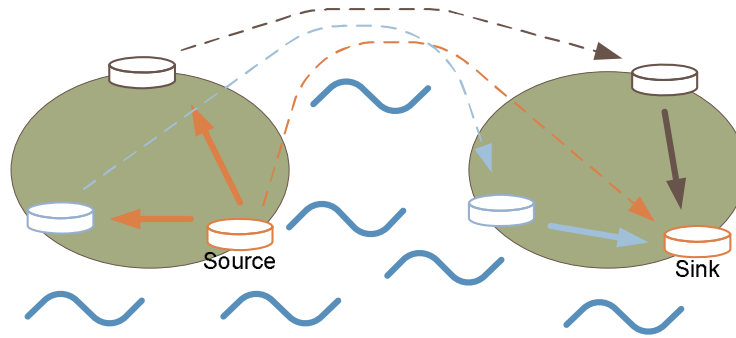


Fig. 3: The devices on the island of the source and the sink communicate cooperatively.

3 Network Coding

Network coding is a network paradigm that allow for a completely different view of the flow of information in a network [2, 3]. Network coding can be implemented in several different ways [4, 5] and used for several different applications [6]. We consider linear network coding based on Galois field arithmetic as it is the most commonly used and well developed approach. Here we first provide a slightly simplified view on network coding to enhance readability and sum up important properties. The interested reader is referred to [7, 8] for an introduction to network coding. Afterwards we explain how network coding may be beneficial for the; complexity, throughput, reliability, security and interoperability in the presented scenarios.

In a traditional network data to be send from a source via some network to a sink is divided into a number of packets N and transmitted one at a time. This approach is called store-and-forward or routing and as the name suggests nodes in the network receive packets and forward these without modifying the content of the packets. If reliable transmission is required each of these packets must be received and acknowledged by the intended sink. If not *all* N packets are received at the sink the source must retransmit the lost packet.

In network coding some additional operations are introduced namely; encoding, recoding, and decoding. At the source the original data is divided into the same N packets as in the traditional approach. However from these N packets new packets that are combinations of the N original packets can be created or *encoded*. The number of unique packets that can be encoded is generally much higher than N . The source can then transmit these packets to other nodes in the network which may in turn *recode* and forward any received *coded* packets. *Recoding* at a node in the network is similar to the initial coding at the source, however the resulting coded packets are only combinations of the subset of packets the node in question holds. In order for the sink to *decode* the original data it must receive *any* N independent coded packets and inverse the performed encoding operations.

Complexity: Network coding can significantly simplify the error correction system as the sink only need to receive N independent coded packets instead of N specific original packets. This approach can be used to reduce the complexity of both the intra- and inter-island communication.

Throughput: It has been shown that network coding satisfy the Max-flow min-cut theorem even in cases where traditional store-and-forward does not [2]. This theorem states that the maximum achievable flow in a network is limited by the bottleneck and thus there exists a network coding solution for all networks that achieves the maximal theoretical throughput. We cannot hope to do any better than this but note that such a solution may not always be easy to identify in a distributed manner.

Reliability: Network coding provides reliability by spreading the data maximally in the network. Therefore if a node fails the transmission can continue unaffected although at reduced speed.

Security: As transmitted packets are coded network coding naturally becomes an interesting concept when security in wireless networks is considered. If only the source and sink knows how the data was encoded no other nodes can decode the data. However the two end nodes are still faced with the traditional key exchange problem.

Interoperability: Network coding has been proposed for implementation on all layers of the network stack. However so far implementations have only been developed for the data link, transport, and application layer [4, 9, 10]. Implementing network coding on the application layer allows for deployment in existing networks agnostic to the underlying technologies. Thus network coding can be deployed without concern for interoperability as long as a common protocol specification is agreed upon.

Network coding provide many benefits however it also presents us with its own set of challenges of which we will consider some related to practical implementation.

4 Challenges and Considerations

Different scenarios and applications possess different requirements and thus the chosen network coding solution should reflect this. Data is coded in network coding and thus we must ensure that the coding throughput is sufficiently high which have proved to be a nontrivial problem [11]. In linear network coding primarily two properties guards the performance characteristics namely the *field size* and the *generation size* [7]. The field size specifies the size of the underlying Galois field and generally the complexity of the coding operations increases with the field size. The generation size specifies how many packets are combined into one coded packet and thus as more computations are needed per packet the throughput decreases as the generation size increases. In addition the generation size influences the delay at the sink because all data in one generation must be decoded before any of it is useful. Thus the minimum achievable delay is increased from one packet to the generation size. Therefore in applications such as

video or audio streaming the delay requirement limits the acceptable generation size whereas in file transfers this is not the case. This indicates that a low field size and generation size should be used, unfortunately this contradicts with the network performance which increases with the field and generation size [12], see Figure 4. We note that if we choose the lowest possible field and generation size linear network coding degenerates into broadcasting.

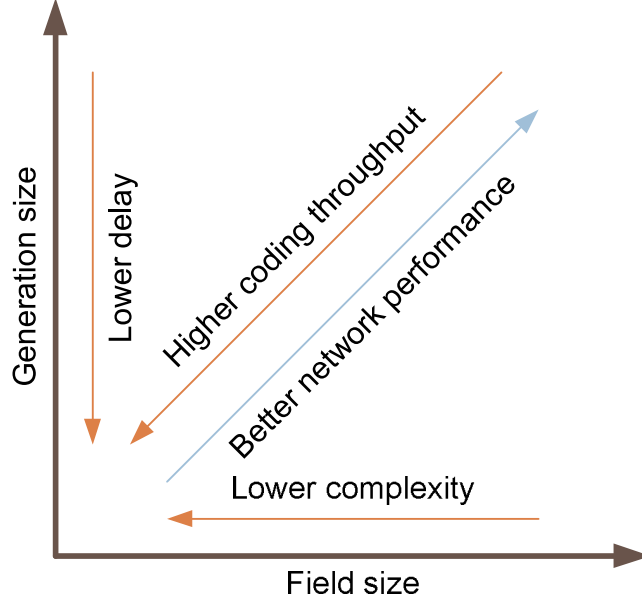


Fig. 4: Tradeoffs depending on the field and generation size.

Additionally the coding throughput will influence the energy consumption because as performance of the coding decreases the CPU utilization increases which leads to increased energy usage.

This work has presented an approach for interconnection of ubiquitous island through the use of cooperation and network coding. We have briefly presented simple cooperation approaches and explained how communication among islands can be improved through cooperation. To decrease the complexity of cooperative strategies we consider network coding and point out some of the benefits it provide. Finally we reflect on some of the problems that must be solved before network coding can be deployed.

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